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NASA TECH BRIEF

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Electrocardiogram Signal Analyzer

An algorithm based upon a Taylor series expansion of the Fourier transform has been developed and used for detection of cardiac arrhythmias in a real-time electrocardiogram (ECG) signal. The algorithm is based on the following:

The Fourier transform is defined as

$$F(\omega) = \int_{-\infty}^{\infty} f(t)\exp(-j\omega t)\,dt \tag{1}$$

When it is expanded in a Taylor series about the point $\omega = 0$, the following infinite series results:

$$F(\omega) = \sum_{k=0}^{\infty} F_k(0)\frac{\omega^k}{k!} \tag{2}$$

where the coefficients

$$F_k(0) = \left.\frac{d^kF(\omega)}{d\omega^k}\right|_{\omega=0}.$$

Using equation 1 to evaluate $F_k(0)$ provides

$$F_k(0) = (-j)^k \int_{-\infty}^{\infty} t^kf(t)dt \tag{3}$$

Now a single cycle (beat) can be represented by a pulse f(t) starting at $t = 0$ with a duration T, i.e.

$$f(t) = \begin{cases} f(t) & 0 \leqslant t \leqslant T \\ 0 & \text{otherwise} \end{cases}$$

For such a pulse, equation 3 becomes

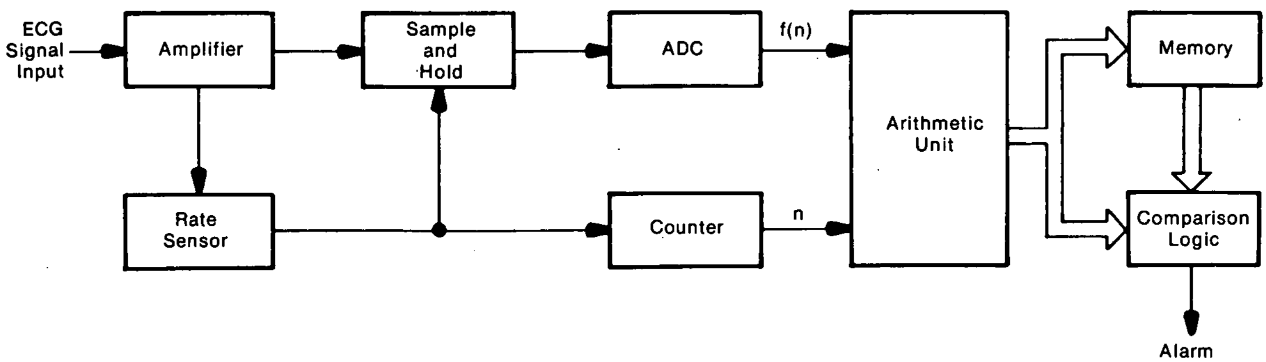
$$F_k(0) = (-j)^k \int_0^T t^kf(t)dt \tag{4}$$

This equation must be converted into a discrete form for digital implementation. Thus, $F_k(0)$ in discrete form becomes

$$F_k(0) = (-j)^k\,\Delta t^{k+1} \sum_{n=1}^{N} n^kf(n) \tag{5}$$

where the integral becomes a sum, dt becomes Δt, $T = N\Delta t$, and $t = n\Delta t$. Equation 5 is rewritten into the form

$$C_k(0) = \frac{F_k(0)}{(-j)^k\Delta t^{k+1}} = \sum_{n=1}^{N} n^kf(n) \tag{6}$$



ECG Signal Analyzer Diagram

(continued overleaf)

It is noted that $C_k(0)$ is a scaled real value of $F_k(0)$ and that $(-j)^k$ and Δt^{k+1} are constants for each k and for a fixed sampling interval Δt. Equation 6 is the form of the algorithm employed in the hardware realization.

The generalized hardware implementation of equation 6 is shown in the illustration. The rate sensor assures that simple rate changes are not identified as arrhythmias. The analog-to-digital converter (ADC) supplies f(n) to the arithmetic unit, and the counter provides the appropriate n value. The arithmetic unit processes n and f(n) to obtain the coefficients, which are supplied to the memory and the comparison logic. A nonagreement between the instantaneous coefficients and the memory output triggers an alarm circuit. The memory may be programed for beat-to-beat update or for longer periods, to indicate gradual degradation of the ECG waveform or for comparison with standard waveforms in ECG screening

The signal analyzer has several special features. It is used to provide information concerning ECG waveforms and their changes entirely without software. This reduces the cost and complexity of automatic monitoring. The algorithm does not require storage of sine or cosine terms, substantially reducing execution time, particularly with respect to fast Fourier-transform analysis. The analyzer is not limited to ECG waveforms. It can be used for processing any signal in order to detect changes in its amplitude or frequency, or to obtain information about its spectral content.

Note:

Requests for further information may be directed to:

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NASA has decided not to apply for a patent.

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Categories: 05 (Life Sciences)
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